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InP/InGaAs Heterojunction Bipolar Transistors Grown on Ge/P Co-implanted InP Substrates by Metal-Organic Molecular Beam Epitaxy

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Abstract

InP/InGaAs Heterojunction Bipolar Transistors (HBTs) have demonstrated excellent high-frequency performance [1-4] and are widely used for optical fiber transmission [5-7]. However, the current mesa HBT structure utilizes a very thick, highly doped n^+InGaAs layer for the subcollector contact. This added mesa height makes multi-level interconnection processes more difficult, which impedes the capability of fabricating compact integrated circuits. In addition, InP has a much higher thermal conductivity than InGaAs, so heat dissipation may be a problem for densely packed circuits with the above structure. This paper reports on InP/InGaAs HBTs grown on Ge/P co-implanted substrates by Metal-Organic Molecular Beam Epitaxy (MOMBE). This embedded subcollector HBT structure offers several advantages for the fabrication of large-scale integrated circuits on InP substrates.

I. Ion-Implantation Conditions

Various elements have been reported for n-type implantation species into InP [8-10]. However, presently there is no obvious evidence to judge which species is better. In this paper, an embedded subcollector layer was formed by co-implanted Ge/P into Fe-doped InP substrates. Multi-energy and multi-dose implantation has been used to optimize the doping profile of both the bulk and surface doping densities. The latter is extremely important to form a good ohmic contact. The conditions are shown in Table I. After ion implantation, the substrates were annealed at 750°C by rapid thermal annealing (RTA). Hall measurements showed low sheet resistance of 54Ω/□, and a very good X-ray diffraction spectrum with a FWHM of 15 arc-secs. This was almost the same as InP substrates without implantation.

Table I. The Ge/P ion-implantation energy and dose for forming embedded subcollector layers.

	Energy (keV)	Dose ($10^{14}/cm^2$)
Ge	100	0.2
	275	0.5
	550	1.3
P	50	0.2
	120	0.5
	250	1.3

II. Device Performance

Figure 1 shows the cross section of the InP/ InGaAs HBT with an embedded, ion-implanted subcollector layer. A 3500Å undoped InGaAs collector layer, followed by 500Å C-doped InGaAs base layer, 850Å n-type InP emitter layer and 1150 Å emitter contact layer were grown on ion-implanted and annealed InP substrates by MOMBE. Figures 2, 3 and 4 illustrate the dc performance of the HBT, including common-emitter dc characteristics, Gummel plots, and beta gain versus V_{BE}, respectively. A low turn on voltage of <0.25V, high breakdown voltage BV_{CEO} of >3V, and high beta current gain of >60 are achieved. These results are very similar to a reference InP/InGaAs HBT grown directly on a regular Fe-doped InP substrate with an n^{+}InGaAs layer for the subcollector contact. In summary, this experiment demonstrates that InP/InGaAs HBTs can be successfully grown on implanted InP substrates with excellent dc characteristics.

Figure 1 Cross section of HBTs with an embedded subcollector

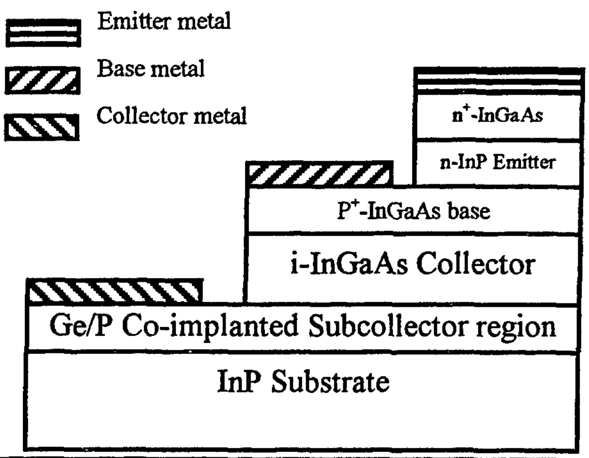


Figure2 Common emitter behavior for HBTs grown on Ge/P co-implanted InP substrates

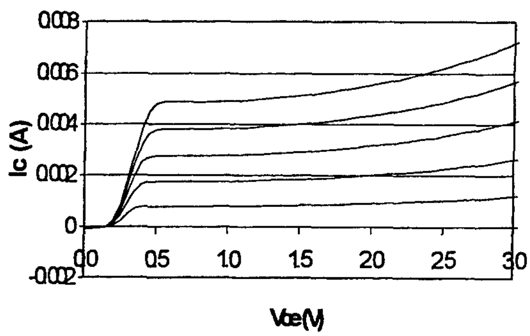


Figure 3 Gummel plot for HBTs grown on Ge/P co-implanted InP substrates

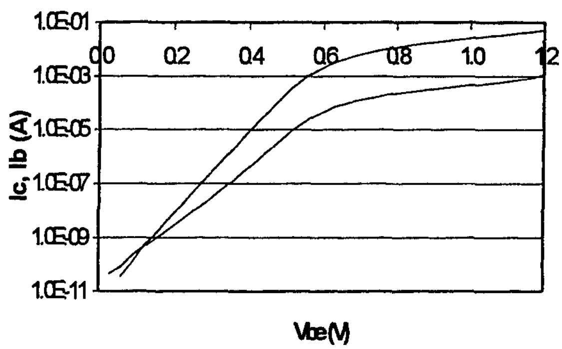
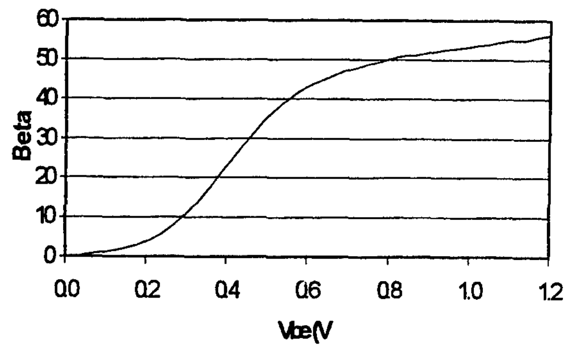


Figure 4 Beta gain vs V_{be} for HBTs grown on Ge/P co-implanted InP substrates



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